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PHYSICAL PROPERTIES OF WATER, AND ITS RELATION TO TREE GROWTH.

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CONSTITUENTS OF WATER.

TEXT-BOOKS on chemistry and physics give us the quantity of hydrogen and of oxygen it takes to constitute a molecule of water; but they do not tell us what part of a millidyne of potential energy, how many millionths of a microcalory of latent heat, what fraction of a millimicrofarad of static electricity, enter into its make-up. It is certain, however, that light, heat, electricity, and other forms of radiant energy, are all stored up in measurable quantities in that same little molecule of water. These are physical elements, and are just as essential to the formation of water as are the chemical elements hydrogen and oxygen. These factors are all essential elements in the constitution of water, and both physical and chemical elements are transferred according to fixed laws to other forms of matter.

CHARACTERISTICS OF WATER.

Water is the great universal solvent of nature. It dissolves and combines with nearly everything in nature, though with varying degrees of force. It has in all cases an ameliorating, a softening, a dissolving influence. Even the hardest rocks finally succumb to its persistent and powerful attacks. Naturally all substances do not yield with equal alacrity to its magic influence. Some substances even have an antipathy for water. Oil, for instance, resists successfully its most powerful onslaughts. And yet water can, with time, destroy an oil film; and in combination with or in presence of other substances, as alcohol, for example, may destroy and absorb the oil itself.

Water is also a ready absorbent of odors and gases. It thus becomes the great purifier of nature.

Pure water is neutral. It is neither acid nor alkaline. It of itself it has neither taste, odor, nor color. All these are readily imparted to it by the substances it holds in solution. Therein lies the secret of good cooking. Taste, odor or flavor, and color are all imparted to it at will.

Water at one place dissolves minerals and takes them up; runs to another carrying the minerals with it; is evaporated and dried up, leaving the minerals behind; returns empty-handed to the starting-point in the form of vapor; is there reconverted into water; returns to the earth and repeats the performance.

Water is the great leveler, not of men but of mountains. In this direction it does a vast amount of work. If the mountains are high, there is much to do; so the water runs swiftly and carries a large amount of material, both in solution and suspension, and hurries away to the sea with its load. Unlike men, the faster it runs the heavier the load it carries. If the land is broad and the mountains and hills are low, there is little to be done; so the water runs leisurely and carries little material except in solution.

Water is the great universal carrier that conveys to every living being, whether plant or animal, the heat, electricity, and chemical elements necessary to its well-being, happiness, and full development. Every drop of water carries with it, wherever it goes, a force that is necessary for the building up of new tissues and new forms. In this respect water is the most important element on the face of the earth. Its constituents also are the most abundant. Hydrogen is one of the most abundant elements; and oxygen is said to compose half the mineral material of the earth and two-thirds of all the animal and vegetable matter.

FORMS OF WATER.

Water, like most substances, may have either of three forms—liquid, solid, or gaseous. There is a fourth form, resulting from the solidifying of the vaporous form without liquefaction and in combination with a large amount of atmospheric air. This we call snow. The air may be squeezed out of it at any time by simple compression. It then becomes true ice.

At ordinary temperatures, between 32° and 212° of the common Fahrenheit thermometer, water is a liquid composed of the two gases named. Hydrogen, the basis, is supposed to be the gaseous condition of a metal, gaseous at all earthly temperatures. It is the lightest of all known gases. It has been liquefied at 400° below zero F., under a very high pressure. No cold has been produced sufficient to liquefy hydrogen at ordinary atmospheric pressure. No cold can be produced on earth that will solidify hydrogen without pressure. Oxygen, the life-giving element, is a gas at all ordinary temperatures. It may be liquefied, but at a very low temperature and under an enormous pressure.

Below 32° F. water becomes solid, and is then called ice. When ice is floating in ice-water it has the same temperature as the water. Before the ice can change to water it must absorb as much heat as is necessary to raise ice-water to 176° F., four-fifths the amount of heat required to boil ice-water with all the ice removed from it.

Conversely, water in freezing gives out four-fifths as much heat as is necessary to raise the same amount of water from the freezing-point to the boiling-point. This explains the mildness of the fall and

winter in regions surrounded by lakes or other large bodies of water. This is a case where the air, which is deficient in natural heat, borrows in the fall and winter large quantities of heat which it must repay next spring and summer from its surplus stock of heat. Does it repay any interest on the borrowed heat? I think not; there appears to be a mutual benefit.

The changing of vapor into rain or snow always causes a large amount of heat to be set free in the air. That explains one of the reasons why, during a snow-storm, with the wind in a damp quarter, as east or northeast, the thermometer never records so low a temperature as it does when the wind is in a dry quarter, as west or north-west.

Snow is a beneficent thing. While in itself it is cold to the ordinary senses, it is an excellent non-conductor of heat and prevents to a large degree the passage of heat from and cold into the underlying earth. It also melts slowly and thus the water becomes absorbed by the soil instead of running off to the sea.

The third natural form of water is as vapor or steam. Steam is the true gaseous condition. Above a temperature of 212° F., liquid water cannot exist except under an increased pressure. Water in being converted into steam absorbs an enormous amount of heat. The heat that water at 212° F. absorbs, in being converted into steam at the same temperature, is sufficient to raise five and one-half times the same quantity of water from the freezing-point to the boiling-point.

Steam is converted into vapor simply by loss of heat on its escape from confinement into the open air. The condition of vapor depends on the amount of heat combined with it. The greater the amount of heat combined with it, the smaller the particles. The amount of heat combined with water accords with the amount of surface. In steam, which contains the greatest possible amount of heat in its composition, the particles are probably reduced to molecules, thus having the greatest possible amount of surface. When steam is superheated—heated above 212° F.—the repulsion of the particles for each other and the distance of the molecules apart are both greatly increased.

On the other hand, as heat is given out in the open air, the particles unite and thus surface is reduced. When much of the heat has been parted with, the vapor particles are large enough to become visible and clouds are formed. With the loss of more heat, mist is formed. When the surplus heat is about all gone, rain is formed.

Water may be converted into vapor at all temperatures below the boiling-point. The amount of heat absorbed by water on conversion into vapor is always great. The greatest evaporation is in the hottest regions and where there is the greatest water surface. This vapor with its contained heat is borne by the winds to cooler regions, where

it is condensed into rain or snow and its surplus heat liberated in the air. Thus is the climate ameliorated at both ends of its journey.

After all, we discover, on reflection, that water, after carrying its load of earth from the mountains to the sea, does not return empty handed. On the contrary, it serves a useful purpose wherever it goes; for, after carrying its load of earth from the mountains to the sea, it carries back with it a load of heat from the sea to the mountains.

Snow and ice, too, may be evaporated and all dried up without liquefaction. This is in case dry winds from the interior blow over them. Evaporation of snow, of course, abstracts heat from the surroundings; but dry cold air is less keenly felt than damp cold air. Besides, the heat taken up is sooner or later returned to the air.

OTHER PROPERTIES OF WATER.

Water has its greatest density at 3.9°C ., equivalent to 39.2°F . Above that it expands slightly for every increase of heat up to 212° . It then suddenly absorbs a very large quantity of heat; increases vastly in size; and is converted into steam. So far as water is concerned, 39.2°F ., might be called its zero of temperature, where it is neither hot nor cold. Below 39° water increases in size for every increment of cold until 32° is reached in fresh water. At 32° it absorbs enough cold to reduce the same quantity of water from 176° down to the freezing point, increases one-eleventh in size, and takes the solid form.

Pure water holds to salt, as in sea-water, with a tenacity equal to four degrees of temperature; that is, sea-water does not freeze at 32° but continues liquid and to increase in size till 28° is reached; then the water freezes, squeezing out the salt. As the amount of salt increases, the degree of cold required to freeze the water necessarily increases. Ice, being only eleven-twelfths the weight of water, floats on the surface of the water.

Then, while ice may and does transmit radiant heat from the sun, as glass does, permitting objects under the ice to become slightly warmed by solar heat, it is a very effective barrier against the admission from the air of cold that comes through convection. It thus acts as a protecting blanket, permitting passage of heat from the sun, yet effectually preventing the escape of heat from the water and preventing the cold above from passing into the water, thus conserving the life below.

The change of form from water to ice is progressive, not sudden like the solidifying of melted lead, iron, or mercury. This is on account of the very large amount of cold which the water must absorb from the air in order to be converted into ice. These are all very important features, upon which the well-being and happiness of all forms of life depend.

For, if the water continued indefinitely to shrink on parting with its heat, and to shrink still further on being solidified, as lard and very many elements and compounds do, all bodies of water must freeze up from the bottom and continue to freeze upward to a level within the influence of the sun's radiation. Whether this freezing would extend to all bodies of water underground suggests an appalling thought.

At the present time the temperature of the water in the great deeps of the Atlantic, South Pacific and Indian oceans is 39.2° , which is water of the greatest density and gravity. The temperature cannot get lower than that without the water at the surface first freezing. If the temperature of the water in the great deeps of the North Pacific is not so low as 39.2° throughout the entire year, it is because there is not sufficient arctic current through Bering strait to cool the entire North Pacific; the antarctic currents have too far to travel, and a great warm stream, the *kuroshiwo* or black current of Japan, passes directly over Kurile Deep, the deepest part of the North Pacific.

And if there were a zone in the ocean where the water should be 39.2° F. at the surface, then all the water along that zone, from surface to bottom, as a wall, would be 39.2° . This is impossible, for then along such a zone the water would be heavier than either north or south of it. It would immediately sink, and the lighter waters from both north and south would flow into its place.

Yet this is precisely what does happen, not as a wall, but as an anticlinal ridge with a gently-falling surface, along a zone from Cape Breton, northeasterly past Newfoundland and Iceland, to the northern coast of Norway; from Sitka, along the Aleutian and Kurile islands, to Yezo; and in the southern ocean all around the earth in the latitude of Cape Horn. Both of those zones are farther northward in July, farther southward in January. They are the zones of frequent storms. Along those zones the lighter waters of 40° F. and upward from the equatorial regions meet and commingle with the lighter waters of 38° and less from the polar regions, becoming an average temperature of 39° or thereabouts. Then, by reason of the increased density and gravity, the waters sink, making room for new waters to flow in from both directions, thus keeping up constant, wide-spread surface currents toward the zones. This is the undoubted cause of both the Gulf stream and the *kuroshiwo*, and the principal cause of all oceanic currents.

TEMPERATURE OF WATER IN OCEANS.

At the bottom, along those zones of greatest density, the water spreads out over the floor of the ocean and flows (1) toward the poles, warming the waters there, melting the ice on its under surface, and displacing the colder, lighter water, which in turn flows back, loose

ice and all, toward the baryhydric (or heavy-water) zone; and (2) toward the equator, where it meets a similar current from the opposite pole, and must eventually become warmed itself in turn. There it underruns and lifts all the waters, rising itself as it becomes warmed and displacing the very warm waters at the surface, which must of necessity flow away in both directions toward the poles. Thus is circulation in the oceans maintained.

What a beneficent provision of the Creator! Could anything be arranged more admirably or with greater wisdom for the welfare and happiness of mankind and all animate creation?

For, suppose for a moment that the greatest density of water were at 60° instead of 39° . The zones of greatest density and most frequent storms, instead of being near the polar circles, as at present, would be near the tropics; in the North Atlantic, say from Florida to North Africa, and in the South Atlantic from Rio de Janeiro to South Africa. Between those zones the surface currents would be from the deepest equatorial or hottest seas. Outside of those zones, in the oceans, all surface currents near the shores would be from the poles; the land on either side would experience arctic weather whenever the wind blew from the ocean.

But there would be no polar ice cap unless the pole were in the heart of a continent. The temperature of the water at the bottom of even a polar sea would be about 60° ; and as the waters there must rapidly cool and come to the surface, the shores of a polar ocean would be more habitable than the interior of a great continent above latitude 50° , or say up to 3000 miles from the pole.

The equatorial seas, by reason of the circulation being restricted to little more than half the quantity of water, would have nearly double the difference in temperature between the bottom and surface that they now have.

The temperature of the bottom of the equatorial seas at present is about 39.2° F.; of the surface about 84.2° . That makes a difference of 45° ; double that would be, say 90° . If, then, the bottom of the seas near the equator were 60° , which would have to be the case, and the surface were 90° higher, the surface would be 150° , too great to support life such as we now know. All oceanic currents, too, would be furious instead of gentle, as at present. Evaporation would be much more rapid than at present and condensation more swift and sudden. There would be no temperate climate on the earth; all would be either frigid or torrid, or both together. The tropics would be the abiding-place of violent storms.

How much, then, must we admire the superlative, the infinite wisdom and goodness of the great Creator in so fashioning us that everything as made is for our greatest enjoyment and welfare.

CAPILLARITY.

Water is the vehicle by which mineral foods of all necessary kinds are carried even to the tops of the tallest trees. There is a power connected with water that is greater within certain limits than the attraction of gravitation. That is capillarity, or, as it is often called, capillary attraction. This depends on two powers—first, *adhesion*, or the attraction of wood or vegetable fiber for water; second, *cohesion*, or the attraction of the particles of water for each other, so that the surface never becomes broken. Every housewife knows that if a wet cloth be left hanging over the edge of a tub the water will creep over and run out. In the case of the cloth there is a great deal of surface for the water to cling to with little space between the various thread surfaces; so that in that case capillarity is stronger than gravitation. I have seen an old cottonwood stump four feet high, its roots in the water during a freshet, two years after the tree had been cut, with the soured water creeping out over the top of the stump, being fed upon by numerous insects, and the water flowing over in such quantity as to trickle down the sides of the stump after some of it had been evaporated.

I do not know the limit where there is a balance between gravity and capillarity; but the diameter of such a capillary tube must be greater than the largest sap duct in wood and much less than half the diameter of a drop of water. The size of the largest capillary tube must depend upon the nature of the material of which the tube is composed and its power of adhesion to water. Of several substances the relative power of attraction for water is as follows, the one having the greatest attraction being first: Salt, wood or carbon fiber, sand, glass, loam, chalk, iron filings, shale, unburnt clay, tin. Clay and shale may even repel water and be impervious to it if they contain oil in any quantity and no sand. A small percentage of salt in earth greatly increases its capacity to admit water.

The power of capillarity also depends much on temperature. Thus, water that will scarcely enter or flow in capillary tubes just above the freezing-point will flow readily at 50° F., and still more rapidly at 80°.

STRUCTURE OF WOOD IN TREES.

The wood of trees is constructed in the form of cells. Wood cells are from a fraction of a millimeter up to several inches in length, and very small, even microscopic, being 10 to 50 microns in diameter, equivalent to 500 to 2500 transversely to the linear inch. They usually taper to points and lap over so as to break joints; but sometimes they end in the same plane so as to form a joint, in stems, as in grasses and polygonums; at the ground, as in tumbleweeds; at the insertion of a leaf, leaflet, stem of a flower, fruit, etc., so as to break

off at maturity; or at the end of a year's growth in the twigs of trees, as in cottonwood or elm. Except in the main branches of such trees the cells often continue for a few years to end at the same place, the joint or ring. Eventually, if the twig be not shed with the leaves, the cells lap over and the ring disappears.

STRUCTURE OF EVERGREEN TREES.

In all the evergreens (conifers) the cells are comparatively large, uniform, and arranged in remarkably straight rows radially; the radial rows of cells are very close together, making all cell-walls thin. In many species the wood cells are formed at all seasons of the year with about the same rapidity; yet the wood of winter is decidedly harder, more compact, and of a higher color than that of spring and summer, thus making the rings quite as easily counted as in deciduous trees, or those having annual leaves. The resin ducts are much larger than the cells, being from 80 to 160 microns in diameter; are scattered and irregular, and most generally in the outer though sometimes in the inner part of the rings. The radial plates or medullary rays are very narrow and thin, consisting of two to fifteen or more horizontal parallelepipedal cells radially extended and laid in a single series vertically, like bricks set on edge lengthwise in a wall, rarely two or three series together, and extending from the pith or from some place in the interior of the tree to and sometimes slightly into the bark. These cells carry food from the elaborated sap in the space between the wood and bark and from the inner layers of bark to the interior of the tree, to feed and strengthen the cells previously formed. They also strengthen the wood of the tree by crossing the regular grain and binding the rings.

In megacellular trees, such as common hemlock, bald cypress, noble fir, coast redwood, and sugar pine, which have the largest cells of any of the evergreen trees, the cells measure thirty-five to forty-five microns in cross section tangentially to the tree, and from thirty to fifty microns radially; and there are from 300,000 to 600,000 cells to the square inch. These can be readily seen, but not readily counted, with the unaided eye.

In mesocellular trees, such as giant redwood, Monterey cypress, most of the firs, the spruces, and nearly all the pines, the cells measure twenty-five to thirty-five microns tangentially, and twenty to forty microns radially; and are 600,000 to 1,200,000 cells to the square inch. These cannot be counted without a lens.

In microcellular trees, such as mountain hemlock, Pacific coast cypress, California red and white fir, Pacific yew, and all the cedars and junipers, the cells measure fourteen to twenty-eight microns in diameter either way; and are 1,200,000 to 2,500,000 cells to the square

inch. One of the finest-grained woods of all is sweet-fruited juniper, whose cells measure twelve to sixteen microns across, either radially or tangentially; and there are from 2,500,000 to 3,000,000 cells to the square inch. These can scarcely be seen with the naked eye and cannot be counted without the aid of a good compound microscope.

The tallest trees are those having medium-sized cells, capillarity being less in the larger cells, and trees with finer cells, such as the cedars and junipers, having less capacity and requiring a highly specialized food, which is taken only in small quantity. Besides, the sap is very heavy to start with in such trees, requiring and receiving very little evaporation in elaboration. This accounts, too, for the smallness of the leaves and the exceedingly slow growth of such trees.

In almost all spring and summer wood of coniferous trees the cells are extended or broadened radially; in autumn and winter wood, on the other hand, the cells are compressed radially, being less than half the breadth of the early cells. The breadth of the cells tangentially to the tree is limited by the distance apart of the radial plates. This is very uniform, though slowly increasing from year to year until a limit is reached; then a cell divides radially and a new radial row of cells and a new set of radial plates appear. Usually there are from two to five or six radial rows of cells at any horizon between two radial plates; in the latter case the formation of a new radial plate reduces the number of rows between plates to two or three. One-fourth of an inch higher up or lower down in the tree the radial plates are in new positions relatively to the vertical cells.

The following table gives (1) the number of cells, (*a*) tangentially and (*b*) radially, across the field of the microscope in cross-sections of the various species of woods named. From these data are calculated (2) the measurements, (*a*) tangentially and (*b*) radially, of the cells, in microns or thousandths of a millimeter; (3) the number of cells in a square millimeter; (4) the number of cells in a square inch, and (5) the grade of fineness of the grain of the wood, "(1)" being coarse or megacellular, "(2)" medium or mesocellular, and "(3)" fine or microcellular. Numerous examples were taken of each kind of wood and a general average taken. Measurements of cells are of the cells complete, including walls; measurements of ducts are of the passages only.

Instrument used: Bausch & Lomb compound, with substage condenser and no micrometer; eyepiece, one inch; objective, three-fourths of an inch; draw-tube closed; diameter of field, 1,587 to 1,610 microns, almost exactly one-sixteenth of an inch. Woods used: Hough's sections of American woods.

COMPARISON OF CELLS OF VARIOUS EVERGREENS.

(Diameter of field, 1.6 mm.=.0625 inch.)	Number of cells across field.		Diameters of cells, in microns.		Number of cells to square millimeter.	Number of cells to square inch.	Grade.....
	Tang.	Rad.	Tang.	Rad.			
No.							
1. <i>Abies amabilis</i> , red silver fir.....	54 60 69	54 62 67	29 26 23	29 25 23	1,492	962,576	(2)
2. <i>Abies balsamea</i> , balsam fir. (Pits: outer diameter, 16 microns; inner diam., 4 mic., approx.)	52 55 57	42 48 54	30 29 27	38 33 29	1,388	895,840	(2)
3. <i>Abies concolor</i> , white fir. (Depth of annual rings from 10 cells radially=.2 mm. to 330 cells=7 mm.)	60 70 80	60 80 93	26 23 20	26 21 17	2,198	1,417,760	(3)
4. <i>Abies grandis</i> , great silver fir.....	43 50 64	40 54 75	37 32 25	40 29 21	1,182	763,904	(2)
5. <i>Abies magnifica</i> , great red fir. (Pits: outer diam., 16 mic.; inner, 5 mic.; diam. of resin ducts, 78 mic.)	58 64 72	68 74 78	27 25 23	23 21 20	2,083	1,342,976	(3)
6. <i>Abies nobilis</i> , noble fir.....	40 45 48	38 41 46	40 35 33	42 39 34	732	472,320	(1)
7. <i>Chamaecyparis lawsoniana</i> , Lawson cypress, "Port Orford cedar."	51 66 72	52 60 69	31 24 22	30 27 23	1,504	969,680	(2)
8. <i>Chamaecyparis nutkatensis</i> , Nootka cypress, "yellow cedar." (Depth of annual rings often 4 cells only=.07 mm.; 32 to 144 rings to the linear inch.)	78 88 96	78 97 106	20 18 16	20 17 15	3,177	2,049,024	(3)
9. <i>Chamaecyparis sphaeroidea</i> , white cedar. (Pits small, about 18 mic. in diam.)	63 69 77	64 70 81	25 23 21	25 23 20	2,002	1,290,240	(3)
10. <i>Cupressus arizonica</i> , Arizona cypress.....	87 95 106	75 85 96	18 16 15	21 18 16	3,229	2,089,000	(3)
11. <i>Cupressus macnabiana</i> , cypress.....	65 70 75	65 76 94	24 23 21	24 21 17	2,196	1,419,760	(3)
12. <i>Cupressus macrocarpa</i> , Monterey cypress. (Pits: inner diam., 3 to 5 mic.; outer, 13 mic.; average diam. of resin ducts, 112 mic.)	56 60 65	56 63 70	28 26 24	28 25 23	1,500	967,680	(2)
13. <i>Juniperus californica</i> , sweet-fruited juniper. (Pits: inner diam., 3 mic.; outer, 11 mic.; interspaces, 0 to 6 mic.)	80 97 112	95 103 112	20 16 14	17 15 14	3,925	2,531,328	(3)
14. <i>Juniperus occidentalis</i> , Western juniper. (Pits: inner diam., 3 mic.; outer, 11 mic.; interspaces, 0 to 6 mic.)	84 94 104	84 100 103	19 17 15	19 16 15	3,588	2,310,144	(3)
15. <i>Juniperus pachyphloea</i> , thick-barked juniper. (Pits: inner diam., 3 mic.; outer, 12 mic.; interspaces, 0 to 12 mic.)	87 94 104	84 100 108	18 17 15	19 16 15	3,660	2,359,040	(3)
16. <i>Juniperus virginiana</i> , red cedar. (Pits: inner diam., 3 mic.; outer, 12 mic.; interspaces, various.)	82 85 95	72 80 87	19 19 17	22 20 18	2,760	1,781,760	(3)
17. <i>Larix americana</i> , tamarack. (Pits: outer diam., 17 mic.; inner, 3 to 5 mic.; interspaces, 4 mic.)	52 57 65	46 56 72	30 28 24	34 28 22	1,384	890,024	(2)
18. <i>Larix occidentalis</i> , Western tamarack. (Pits: inner diam., 3 to 6 mic.; outer, 16 to 22 mic.; interspaces, 3 mic. or more.)	44 51 55	48 51 55	36 30 29	33 30 29	1,012	652,800	(2)

COMPARISON OF CELLS OF VARIOUS EVERGREENS—CONTINUED.

(Diameter of field, 1.6 mm.=.0625 inch.)	Number of cells across field.		Diameters of cells, in microns.		Number of cells to square millimeter.	Number of cells to square inch.	Grade.....
	Tang.	Rad.	Tang.	Rad.			
No.							
19. <i>Libocedrus decurrens</i> , incense cedar.....	48 58 68	65 75 90	33 27 23	24 21 18	1,770	1,143,300	(2)
20. <i>Picea alba</i> , white spruce.....	47 56 62	52 62 69	34 29 25	30 25 23	1,334	858,880	(2)
21. <i>Picea engelmanni</i> , Arizona spruce.....	63 69 79	56 69 82	25 23 20	28 23 19	1,940	1,254,144	(2)
22. <i>Picea nigra</i> , black spruce. (Pits: outer diam., 13 mic.; inner, 4 mic.; resin ducts, 80 mic.)	53 58 60	54 62 73	30 27 26	29 25 22	1,210	780,160	(2)
23. <i>Picea sitkensis</i> , Sitka (tideland) spruce. (Pits: inner diam., 4 mic.; outer, 19 mic.; interspaces, 0 to 10 mic.; pits occasionally overlap.)	40 45 50	45 60 68	40 35 32	35 26 23	1,328	885,660	(2)
24. <i>Pinus attenuata</i> , knob-cone pine. (Resin ducts, 100 mic. in diam., mostly in autumn and winter part of the rings.)	54 69 74	55 66 78	29 23 21	26 23 20	1,728	1,115,136	(2)
25. <i>Pinus clausa</i> , sand pine. (Resin ducts numerous, brown, mainly in inner part of annual rings.)	60 61 64	60 62 64	27 26 25	27 26 25	1,500	968,192	(2)
26. <i>Pinus contorta</i> , twisted pine. (Resin ducts light brown, mainly in outer part of annual rings.)	50 64 68	61 63 65	31 25 23	26 25 24	1,520	983,808	(2)
27. <i>Pinus coulteri</i> , big-cone pine. (Cell-walls very thin; resin ducts, 120 mic., in autumn wood.)	45 50 60	45 55 62	35 32 26	35 29 25	1,134	732,160	(2)
28. <i>Pinus echinata</i> , short-leaf yellow pine. (Resin ducts amber, in middle of rings.)	44 50 56	54 59 62	36 32 28	29 27 25	1,150	742,400	(2)
29. <i>Pinus lambertiana</i> , sugar pine.....	44 50 55	42 54 59	36 32 29	38 29 27	1,032	665,600	(2)
30. <i>Pinus monophylla</i> , single-leaf pinon.....	50 54 60	61 79 87	32 29 26	26 20 18	1,660	1,070,080	(2)
31. <i>Pinus monticola</i> , mountain pine. (Resin ducts white, in outer part of rings.)	45 53 61	50 55 60	35 30 26	32 29 26	1,156	746,240	(2)
32. <i>Pinus muricata</i> , pickle-cone pine.....	54 58 61	52 59 66	29 27 26	30 27 24	1,358	876,032	(2)
33. <i>Pinus palustris</i> , long-leaf yellow pine. (Pits: outer diam., 20 to 24 mic.; inner, 4 to 7 mic. Resin ducts, 80 to 160 mic.)	44 52 58	48 53 60	36 30 27	34 30 26	1,092	705,024	(2)
34. <i>Pinus ponderosa</i> , bull pine. (Resin ducts, 140 mic. diam., burnt-sugar color.)	40 44 54	48 55 61	40 36 30	33 29 26	1,005	647,680	(2)
35. <i>Pinus radiata</i> , Monterey pine. (Resin ducts, 130 mic. diam., brown; resin in ducts, yellow.)	48 52 64	60 66 76	33 30 25	26 24 21	1,464	943,360	(2)
36. <i>Pinus resinosa</i> , "Norway" pine. (Resin ducts, 95 mic., numerous, yellow.)	56 68 83	51 62 88	28 23 19	31 25 18	1,833	1,183,488	(2)

COMPARISON OF CELLS OF VARIOUS EVERGREENS — CONCLUDED.

(Diameter of field, 1.6 mm.= .0625 inch.)	Number of cells across field.		Diameters of cells, in microns.		Number of cells to square millimeter.	Number of cells to square inch.	Grade.....
	Tang.	Rad.	Tang.	Rad.			
No.							
37. <i>Pinus rigida</i> , pitch pine. (Pits: inner diam., 4 mic.; outer, 21 mic.)	54 59 66	54 61 67	29 27 24	29 26 24	1,450	934,460	(2)
38. <i>Pinus sabiniana</i> , gray-leaf pine. Annual growth, 6 to 12 mm. One radial row of $\frac{7}{8}$ in. in an an. ring contained cells as follow, in seven successive fields, counting outward: 44, 46, 49, 53, 60, 70, 83; total, 405.)	48 58 68	46 65 76	33 27 23	34 25 21	1,436	920,576	(2)
39. <i>Pinus strobus</i> , white pine. (Resin ducts small, 100 mic., white.)	48 51 54	47 50 55	33 31 29	34 32 28	1,034	665,856	(2)
40. <i>Pinus virginiana</i> , scrub pine.....	60 63 66	62 70 78	26 25 24	26 22 20	1,750	1,128,960	(2)
41. <i>Pseudotsuga douglasii</i> , Douglas spruce...	52 63 79	57 75 112	30 25 20	28 21 14	2,084	1,347,840	(3)
42. <i>Pseudotsuga macrocarpa</i> , big-cone spruce,	45 51 57	55 59 63	35 31 28	29 27 25	1,196	770,303	(2)
43. <i>Sequoia gigantea</i> , giant redwood.....	44 48 52	40 48 57	36 33 30	40 33 28	914	589,824	(1)
44. <i>Sequoia sempervirens</i> , coast redwood....	31 33 35	31 35 41	51 48 45	51 45 39	472	304,128	(1)
45. <i>Taxodium distichum</i> , bald cypress. (Pits: inner diam., 4 mic.; outer diam., 12 mic.)	47 54 60	45 50 54	34 29 26	35 32 29	1,072	691,200	(2)
46. <i>Taxus brevifolia</i> , Pacific yew.....	62 75 90	73 80 84	25 21 18	22 20 19	2,382	1,537,024	(3)
47. <i>Thuja occidentalis</i> , arbor-vitæ.....	69 84 94	64 78 83	23 19 17	25 21 19	2,293	1,480,576	(3)
48. <i>Thuja plicata</i> , Pacific arbor-vitæ.....	63 68 72	65 71 76	25 23 22	23 22 21	1,914	1,235,968	(3)
49. <i>Tsuga canadensis</i> , hemlock. (Depth of annual ring, 240 cells, averaging one cell a day for eight months, in each radial row of cells.)	48 55 60	50 55 58	33 29 26	32 29 27	1,180	760,320	(2)
50. <i>Tsuga heterophylla</i> , Western hemlock....	47 54 60	51 66 84	34 30 25	31 24 19	1,464	943,360	(2)
51. <i>Tsuga pattoniana</i> , mountain hemlock....	61 72 84	59 76 94	26 22 19	27 21 17	2,204	1,420,832	(3)
52. <i>Tumion californica</i> , California nutmeg...	44 50 54	40 46 50	36 32 29	40 34 32	876	564,480	(1)
53. <i>Tumion taxifolia</i> , stinking cedar.....	44 51 55	54 57 68	36 31 29	29 28 23	1,192	768,000	(2)

STRUCTURE OF DECIDUOUS TREES.

Deciduous trees have very fine cells, even microscopic. They range in size from 12 to 25 microns in diameter, and are from 1000 to 2100 to the linear inch. Besides the cells proper, or microcells as they really are, all deciduous trees have larger pores or crude sap ducts, which vary greatly in size in the different kinds of wood, being very large in oak, hickory, ash, and elm, and small in maple, poplar, apple, boxwood, and horse-chestnut.

The ducts, although differing greatly in diameter, are all well within the limits of capillarity. The larger ducts are provided at short intervals with valves to prevent sagging of the sap.

Among the woods having ducts above the average in size are willow, the diameters of whose ducts are from 50 to 110 microns, with much intervening cellular tissue; hickory, in which the spring ducts are 230 microns across and the ducts of the summer and autumn wood 60. In summer grape, in which the spring ducts are very large and oval, they measure 240 microns tangentially and 300 radially. These occupy apparently about one-third the space of the wood.

In many trees there are two sorts of ducts, the full philosophy of which I have not studied. In the spring formation of wood the ducts are very large, and may be one or several between each two successive radial plates. These ducts are usually well supplied with valves. The valves are often squarely across a duct, but oftener stand through the tube at every conceivable angle and are by no means always a uniform plane, but are frequently a spherical segment. They occasionally run parallel with the walls of the duct and subdivide it into several smaller tubes. Valves contain no pits; they are thin and require none. When straight across a duct they are usually at nearly regular distances. Frequently two ducts are side by side for a short distance, separated by a septum. Septa are provided with pits for the free transmission of liquids from one duct to another. In the summer and autumn wood the ducts are small, though varying much in size. These are sometimes solitary, sometimes grouped regularly and separated by pitted septa. These tubes contain no valves. Woods having the two kinds of ducts will be distinguished nominally by calling them heterotracheal, and the two kinds of ducts will be called macropores and micropores.

As examples of heterotracheal wood may be cited oak, hickory, chestnut, and catalpa. In white oak, for example, as in hickory, the larger ducts, or macropores, which occur in the spring growth of the wood, are 200 to 300 microns in diameter; the smaller ducts, or micropores, which are in the solid summer and autumn part of the rings, are 40 to 80 microns. In catalpa, also, the sizes vary much; the macro-

pores average 200 microns; the micropores vary from 25 to 80 microns. The true cells, or microcells, are unusually large, about 21 microns. In chestnut the ducts are strongly oval in cross-section, with the longer diameter radial to the tree, as usual in deciduous trees; the macropores measure 320 microns the shorter way and 400 the longer way; the micropores average about 50 microns. The cells are 20 microns, which is very large.

In another group of trees the pores or ducts are all of one kind, though manifestly there are great differences of size. As prominent examples of one division of these may be cited maple, sycamore, cottonwood, and willow. In these the ducts are grouped into sets separated by thin cellular walls or septa. The number of ducts in a group varies from two to about five or six, seldom more. The distance between groups is usually much more than the breadth of a group. These are close-grained woods. In maple the ducts seldom exceed 75 microns, and occupy apparently about one-ninth of the wood. In sycamore the ducts are somewhat larger, but are crowded between the very strong plates; they occupy about one-seventh of the space of the wood. In cottonwood and willow the ducts are more uniformly distributed, are more numerous, and occupy about one-sixth of the wood. As a distinction for this class of woods they will be called gamotracheal.

In a third group, which comprises all our fruit-trees and some others, the ducts are all small, solitary, and very uniformly distributed. These are our closest-grained woods. For distinction, they will be called dialytracheal. In apple the ducts are elliptic to oval, measure 40 microns radially and four-fifths as much tangentially, and occupy about one-eighth of the space. In cherry the ducts are 30 to 60 microns, and occupy one-seventh to one-sixth of the space. In plum the ducts are quite equidistant; they vary in size from 30 to 50 microns tangentially and 30 to 60 radially, and occupy one-seventh of the wood. The rays are strong in plum. In pear the ducts vary from 25 to 45 microns and occupy one-eighth of the space. The wood is therefore about as close-grained and solid as apple wood. The cells proper, which are exceedingly fine, not exceeding 12 to 14 microns, are 1800 to 2100 to the linear inch, making possible 3,750,000 cells to the square inch. But, as there are 50,000 ducts to the square inch, occupying the space of ten times as many cells, it will be necessary to deduct about half a million from this estimate, still leaving 3,250,000 cells and 50,000 ducts to the square inch.

The rays or radial plates in the deciduous trees consist of strong, thin, lenticular, horizontal, radial bundles of cylindrical, cylindroidal, parallelepipedal, or even tabular cells placed on edge, and superposed

either in straight vertical rows or promiscuously, the lenticels being from one cell thick at the lower and upper edges to 6, 10, 15 or more cells in the thickest part, and from 50 to 500 or more cells in height. Rays are sometimes one-fourth of an inch or more in breadth (height), and often contain several thousand cells in a radial bundle or plate. Such plates are very large and strong and hard, as in oak, sycamore, chestnut, water locust. As in evergreen trees, the primary rays originate in the pith. All rays end in the bark.

The comparative size of the ducts in a tree in any year seem to be inversely proportional to the leafage for that year. The number or size of the macropores does not vary much from year to year; but greater leafage in any year causes a greater thickness of summer and autumn wood with its accompanying micropores to be formed. Less leafage causes less solid wood to be built up; so that the relative amount of spring wood is greater. In trees that live near or by the edge of water, where the food supply is unvarying at all seasons, the ducts are of uniform size and the wood of uniform texture throughout the year. The same is true of trees that grow on mountain sides, where the supply is constant and uniform, though never superabundant.

MICROSCOPIC STRUCTURE OF DECIDUOUS TREES.

The following tables show to some extent the microscopic structure of the several kinds of wood named. The character of the ducts, radial plates and pits are sometimes shown. Diameters of the ducts and cells, both tangentially and radially, and the proportionate space occupied by the ducts and empty cells, are generally shown. The specific gravity of the various woods are shown for purposes of comparison. Measurements are given in microns, of which there are 25,400 to the linear inch. Measurements are not absolute, but only approximate and comparative. Minor and major figures are usually given, not absolute extremes. Magnification the same as in studying the evergreens.

No.	HETEROTRACHEAL WOODS. (Woods in which the spring and summer ducts are unlike ; macro-pores generally filled with valves.)	Diameters of macro-pores or spring ducts, in microns.		Diameters of macro-pores or summer ducts, in microns.		Relative space occu- pied by ducts.	Diameters of cells, in microns.		Specific gravity.....
		Tang.	Rad.	Tang.	Rad.		Tang.	Rad.	
1.	<i>Ailanthus glandulosa</i> , ailanthus. (Autumn cells solid; pits minute, very numerous, generally scattered).	160 250	200 300	26 40	24 46	10:76	10	15	.65
2.	<i>Castanea dentata</i> , chestnut. (Pores and cells large; pits small, in straight longitudinal lines.)	120 320	180 380	25 45	30 70	10:64	16	22	.59
3.	<i>Catalpa bignonioides</i> , catalpa. (All ducts full of valves in every direction; pits areolate, numerous, scattered.)	100 160	120 220	30 60	25 80	10:54	14 17	18 22	.45
4.	<i>Chilopsis saligna</i> , "desert willow" (a sort of catalpa). (Pits areolate, scattered).....	100 150	120 180	50 75	60 90	10:56	12	18	.46
5.	<i>Fagus americana</i> , (white) beech. (Rays strong, slightly reddish; micropores few, macro-pores running into autumn; pits small, scattered.)	50 210	30 70	20 30	20 30	10:90	14	16	.69
6.	<i>Fraxinus americana</i> , white ash. (Pits large, irregular).....	120 150	150 250	25 50	30 60	10:68	16 18	20 24	.65
7.	<i>Fraxinus nigra</i> , black ash. (Pits minute, irregular).....	100 150	120 170	25 40	25 50	10:64	16 18	18 22	.63
8.	<i>Hicoria alba</i> (Raf.), shagbark hickory. (Micropores few; pits about 5 microns, in recti-linear rows; tangential brown lines in autumn wood.)	100 200	160 300	25 40	25 60	10:84	15	16	.83
9.	<i>Hicoria amara</i> (Raf.), bitternut. (Micropores few; summer and autumn wood filled with continuous tangential brown lines, as in all the hickories.)	120 220	230 350	25 50	30 60	10:76	15	16	.75
10.	<i>Hicoria maxima</i> (Raf.), mockernut. (Pores filled with valves; tangential lines and pits as in <i>H. alba</i> .)	100 150	120 180	20 50	25 60	10:84	15	16	.82
11.	<i>Hicoria porcina</i> (Raf.), pignut. (Lines and pits as in <i>H. alba</i>).....	120 210	200 330	30 50	30 65	10:82			.82

MICROSCOPIC STRUCTURE OF DECIDUOUS TREES—CONTINUED.

No.	HETEROTRACHEAL WOODS. (Woods in which the spring and summer ducts are unlike; macro-pores generally filled with valves.)	Diameters of macro-pores or spring ducts, in microns.		Diameters of summer ducts, in microns.		Relative space occu- pied by ducts.	Diameters of cells, in microns.		Specific gravity.....
		Tang.		Tang.			Tang.	Rad.	
		150	220	30	30	Rad.			
12.	<i>Hicoria sulcata</i> (Britt.), big shellbark hickory. (Markings and pits as in <i>H. alba</i>)	220	340	50	70	10:80			.80
13.	<i>Juglans cinerea</i> , butternut. (Radial plates weak; pits large, scattered; tangential brown lines broken.)	100	140	35	40	10:48			.45
14.	<i>Juglans nigra</i> , black walnut. (Macro-pores filled with valves; macro-pores very few; pits trap- ezoidal, lunate, etc., 10 by 7 microns; tangential lines broken.)	180	280	80	90	10:64			.61
15.	<i>Morus rubra</i> , red mulberry. (Ducts compound, practically filled with valves; pits 7, microns, regularly arranged.)	90	110	40	45	10:64			.59
16.	<i>Quercus alba</i> , white oak. (Rays white, very strong, primary rays fully 20 cells thick in mid- dle of plates; macro-pores filled with valves in all the oaks.)	120	120	25	25	10:70		15	.74
17.	<i>Quercus coccinea</i> , scarlet oak. (Pits between ducts oval, areolate, 9 by 7 microns; against the rays about 4 microns, in rectilinear rows, as in all the oaks.)	200	250	60	75	10:70		15	.74
18.	<i>Quercus macrocarpa</i> , bur oak. (Micro-pores grouped in radial areas, growing gradually less toward autumn, as in other oaks; duct pits, 10 microns; ray pits, 4 microns.)	100	180	25	30	10:68		14	.75
19.	<i>Quercus prinus</i> , chestnut oak. (Duct pits oval, areolate, 12 by 9 microns; ray pits oblong to lunate, 6 by 4 microns.)	230	290	50	60	10:72		16	.75
20.	<i>Quercus rubra</i> , red oak. (Rays and ducts as in other oaks; duct pits, 10 by 8; ray pits, 5 to 6 by 4 microns.)	90	120	25	30	10:72		18	.75
21.	<i>Quercus velutina</i> , yellow oak. (Rays reddish brown; pits oval, 10 microns, somewhat regu- larly arranged.)	100	130	25	25	10:62		14	.66
22.	<i>Sassafras officinale</i> , sassafras. (Rays brownish; pits oval, areolate, 12 by 10 microns, some- what regularly arranged.)	240	300	50	60	10:68		14	.71
23.	<i>Ulmus americana</i> , (white) elm. (Macro-pores in single series each year; macro-pores in tan- gential groups, forming connectedly tangential or diagonal lines.)	100	120	20	20	10:44		14	.50
24.	<i>Ulmus pubescens</i> , slippery elm, ("red" elm). (Pits oval, areolate, about 9 by 7 microns, in rectangular rows.)	180	240	25	30	10:58		16	.65
25.	<i>Vitis aestivalis</i> , summer grape. (Macro-pores oval, in one or more distinct tangential rows each year; abundantly furnished with valves; septa between macro-pores tangential, numerous; pits very large, often 30 by 10 microns.)	80	100	30	30	10:62		11	.69
		150	180	50	55	10:28		14	.41
		90	100	25	25			12	
		180	210	50	50			15	
		160	200	45	40				
		320	400	50	80				

MICROSCOPIC STRUCTURE OF DECIDUOUS TREES—CONTINUED.

No.	Ducts usually in radial groups, with septa tangential and more or less longitudinal (vertical).	GAMOTRACHEAL WOODS.	Diameters of ducts, in microns.		Relative space occupied by ducts.	Diameters of cells, in microns.		Specific gravity
			Diameters of ducts, in microns.			Diameters of cells, in microns.		
			Tang.	Rad.		Tang.	Rad.	
26.	Acer negundo, box-elder. (Rays white; pits areolate, irregular).....		32 64	35 75	10.92	18	19	.73
27.	Acer saccharinum, white maple. (Ducts one to five in each group; rays numerous, thin, narrow, and close together; pits rhombic, areolate, 6 microns across, somewhat regularly arranged.)		36 63	38 76	10.79	17	20	.63
28.	Acer saccharum, sugar maple. (Ducts usually single; rays red; pits areolate, variously shaped).....		35 70	35 75	10.85	17	19	.69
29.	Betula lutea, yellow birch. (Pits minute, very numerous).....		60 130	70 150	10.69	18	19	.58
30.	Betula papyracea, canoe birch. (Ducts mostly in pairs at any cross-section).....		35 85	45 95	10.78	18	19	.69
31.	Carpinus caroliniana, "blue beech," hornbeam. (Cells solid).....		25 70	30 80	10.95	15	17	.73
32.	Ilex opaca, holly. (Ducts occasionally solitary).....		20 40	20 45	10.72	16	18	.58
33.	Liriodendron tulipifera, "whitewood," tulip tree. (Cells large; pits oval to oblong, 6 to 18 by 6 microns, regular as the grains of corn on a cob.)		42 84	54 98	10.50	19 21	21 23	.42
34.	Magnolia acuminata, cucumber tree. (Cells very large, empty; pits scalariform, 6 to 60 by 5 microns; interspaces, 3 microns.)		50 100	60 120	10.46	21 25	24 30	.40
35.	Magnolia grandiflora, magnolia. (Valves numerous; pits scalariform, 5 to 40 by 5 microns, regularly arranged.)		30 65	35 60	10.68	20	22	.64
36.	Ostrya virginica, "ironwood," hop hornbeam. (Cells solid; pits oblong, 8 by 5 microns, scattered).....		30 50	30 60	10.105	15	17	.83
37.	Platanus occidentalis, sycamore. (Rays very strong, reddish; pits oblong, 6 by 4 microns, in regular transverse rows.)		60 90	60 100	10.73			.57
38.	Platanus wrightii, Arizona sycamore. (Rays very strong, fully equal in thickness to the interradial spaces, reddish.)		50 80	50 90	10.75			.58
39.	Populus grandidentata, poplar. (Pits large, 10 microns, nearly round, areolate, quincuncially arranged in longitudinal rows.)		45 80	45 90	10.56	18	20	.38

MICROSCOPIC STRUCTURE OF DECIDUOUS TREES — CONTINUED.

	Diameters of ducts, in microns.	Relative space occupied by ducts.	Diameters of cells, in microns.		Specific gravity . . .
			Tang.	Rad.	
GAMOTRACHEAL WOODS.					
Ducts usually in radial groups, with septa tangential and more or less longitudinal (vertical).					
No.					
40. <i>Populus monilifera</i> , cottonwood. (Pits obscurely hexagonal, areolate, 10 by 9 microns, close together, quincuncially arranged.)	40 64	40 72	17	20	.39
41. <i>Populus tremuloides</i> , aspen. (Pits oval, 9 by 7 microns, not close together, quincuncially arranged in rows lengthwise.)	30 70	30 75	18	20	.40
42. <i>Salix alba</i> , white willow. (Pits areolate, 8 microns diam., quincuncially arranged in rows)	40 100	50 120	18	21	.41
43. <i>Salix nigra</i> , black willow. (Pits quincuncially arranged in longitudinal rows).	45 100	50 110	17	21	.43
44. <i>Tilia americana</i> , basswood. (Ducts subdivided by radial and tangential septa; valves frequent; pits small, scattered; ducts with many transverse threads.)	30 75	30 80	17	21	.45

MICROSCOPIC STRUCTURE OF DECIDUOUS TREES—CONCLUDED.

	DIALYTRACHEAL WOODS. Ducts solitary; valves transverse.	Diameters of ducts, in microns.		Relative space occupied by ducts.	Diameters of cells, in microns.		Specific gravity....
		Tang.	Rad.		Tang.	Rad.	
No.							
45.	<i>Cerasus vulgaris</i> , garden cherry	25 50	30 60	10:64	18	21	.61
46.	<i>Cercocarpus parviflorus</i> , mountain mahogany. (Rays numerous, highly colored; pits rectangularly arranged.)	20 50	20 60	10:76	14	16	.74
47.	<i>Crataegus coccinea</i> , scarlet thorn. (Spring ducts larger than summer; pits lunate, 15 by 5 microns)	30 50	30 60	10:76	16	18	.72
48.	<i>Cornus alternifolia</i> , (blue) dogwood. (Cells solid; pits oval, rectangularly arranged; certain ovoid ducts with scalariform vessels instead of pits.)	30 50	30 55	10:74	19	22	.67
49.	<i>Cornus florida</i> , flowering dogwood. (Rays white; pits rectangularly arranged; certain ovoid ducts furnished with scalariform vessels and no pits.)	25 45	25 50	10:84	17	19	.80
50.	<i>Malus communis</i> , apple. (Ducts oval to elliptic; pits small, in regular lines).....	25 40	30 50	10:82-	17	19	.80
51.	<i>Malus coronaria</i> , crab-apple. (Pits oval, 8 microns, rectangularly arranged)	25 45	25 55	10:76	15	18	.71
52.	<i>Padus serotina</i> , wild black choke-cherry. (Ducts normally double or multiple; pits areolate, 9 to 10 by 6 to 7 microns, in regular rows.)	30 60	30 70	10:60	20	25	.58
53.	<i>Prunus americana</i> , wild plum. (Spring ducts larger but of same character as summer ducts; pits somewhat regular.)	30 55	35 60	10:70	18	21	.69
54.	<i>Pyrus communis</i> , pear. (Ducts oval to elliptic; pits small, regular).....	25 40	25 48	10:80	12	14	.81
55.	<i>Sorbus americana</i> , mountain ash.....	30 50	30 70	10:64			.60

CIRCULATION OF THE SAP.

Sap passes from cell to cell through minute oval or circular windows, quite regularly placed, in rectilinear rows when in a duct beside vertical cells; transverse rows when beside the horizontal cells of the radial plates; scattered or in somewhat spiral or diagonal rows when beside a similar duct, and yet differing in character in the different families of trees.

These windows are minute pits with a thin transparent or translucent film of cellulose stretched across. Greatly magnified, a section of duct looks like a section of well-point of a driven well, or like a section of perforated boiler-iron with soap-bubble films across the perforations. Each cell has from four to six rows of these pits communicating with the adjacent cells, being one row to each adjoining cell.

The number of these pits to the inch in a straight line is about the same as of cells of the deciduous trees, say 2000. The diameter of a pit when circular is about four microns; when oblong is about six microns the longer way, four the shorter way. With the marginal ring, or frame of the window, the measurement across a pit is about nine to twelve microns. The ducts often have 50 to 100 or more vertical rows of pits communicating with adjoining cells and ducts. The size, shape and distance apart of the pits in the ducts of any tree is precisely the same as in the vertical cells, but usually much larger than in the ray cells.

Sap flows upward in the ducts of deciduous trees and the cells of coniferous trees, mainly in the sap-wood; downward between the bark and wood and through the inner layers of bark; inward in the radial plates; and permeates all through the cells of deciduous trees, except some of the heart cells, which are filled with wood fiber and various organic substances.

Whatever the diameter of the cell, or whatever its length, water will percolate or creep to the extreme end, even against gravitation, by simple capillarity, aided by osmotic pressure. The bud or leaf of the plant or tree has no such sucking power as has been ascribed to it. It has no sucking power at all. The food comes to the bud or leaf by processes over which it has no control and cannot aid in any way except by making use of the materials that come to it as food. And that it does and does it well.

OSMOSIS.

From cell to cell, water, carrying with it its mineral contents, always of a crystalline nature, leaving bacteria, fungi spores, and albuminoids and colloids behind, passes by a molecular process called osmose, always from a cell containing water of any gravity to a cell

containing water of a greater gravity. A difference of less than one-millionth of the weight of water between two cells is sufficient to cause osmose from cell to cell. This feature, together with the principle of capillarity, as shown in the size of the cell, explains why there is a limit to the height of any tree.

The heaviest water, or sap as we call it, is always in the leaves and bark: because evaporation is there constantly going on and the gravity of the sap thus increased. The sap is prepared in the leaves and bark.

The spongioles, the roots, the pith, the wood, the leaves, the bark, and the fruit of every tree and plant constitute the several departments of a chemical laboratory, in which the sap received is elaborated and converted into the productions peculiar to that plant or that portion of the tree or plant. Carbonic-acid gas is absorbed from the air and combined with the mineralized water taken from the earth to form the various carbohydrates from which all the products of the tree or plant are formed. In case of the tree cacti, as *Opuntia arborescens*, *Cereus giganteus*, etc., much of the water needed is not from the earth, but is absorbed from the air through especially-constructed cells. The sectored clusters of wood cells or vascular tissue are arranged at regular intervals within and completely surrounded, bark and all, by the soft, cellular, parenchymatous tissue of the stem, which is abundantly supplied with chlorophyl, and performs the functions of both leaves and roots. The roots themselves, while they do absorb some moisture and minerals from the earth, are mainly for the purpose of keeping the plants in an erect position.

The spongioles and root-hairs are always hungry and absorb more than the cells can hold. The surplus is pushed back into the cells above, thus aiding the osmotic pressure. They have a selective capacity, and take from the soil, not everything in it, nor everything in the water in the soil, but only those mineral ingredients which are needed for use in the tree or plant. This they do by a faculty analogous to what we call taste in animals. For example, asparagus, the Russian thistle, the atriplexes, some of the goosefoots, and some of the grasses, such as *Distichlis spicata*, *Spartina gracilis*, and finetop salt-grass, thrive in a saline soil, where most other plants could not live. Any plant will live in any soil where the food that it likes is abundant and the food that it dislikes is not too plentiful.

It often happens that two very dissimilar plants grow in the same soil in close proximity without interfering with each other; in fact, they are mutually helpful, for the reason that each one takes from the soil materials that the other does not like and does not want. Beech and maple trees are a case in point. Totally different in their natures, they live harmoniously together and are mutually helpful. It might

be supposed that apple and cedar trees, belonging as they do to totally different families, would be mutually helpful; but in this case there happen to be other biological reasons why they should not be cultivated together. Apple and cherry, apple and peach, or apple and pear should not be cultivated close together, as they both belong to the same botanical family, both secrete prussic acid, and both exhaust the soil of the same chemical ingredients, materials not in the soil in too great abundance, and not at all in some soils. That explains, too, why apple or fruit-trees do not do well in certain soils, and why orchards die out, and why young apple trees will not grow where an old apple tree has died out. Other crops may do well there. It also explains why, in Maryland and eastern Virginia, after the original hardwood forests have been cleared away, or after the land has been cropped to exhaustion, nothing but pines grow; and why, in Michigan and elsewhere, after the native pine forests are cleared away, the land quickly becomes covered with a luxuriant growth of oaks, maple, beech, and other deciduous trees.

WATER FOR POTABLE USES.

Spring- or well-water, containing a small percentage of lime, the smaller the better, so that there is some, seems to be best for potable and culinary uses. Rain-water is not best unless well filtered, for the reason that it contains much that is deleterious, such as decaying insects and their remains; decaying pollen, spores, and other vegetable particles; sand, chalk, and other earthy substances; ammonia, smoke, carbonic acid, and other noxious gases; bacteria, parasites, and the germs of numerous diseases, besides the unspeakable filth that accumulates on roofs between rains. These are all beneficial to vegetation, but are filtered out of it by the earth largely before it sinks eight inches, and almost wholly before it sinks eighteen feet, into the earth. Water falling at the close of a prolonged rain is purer; but water standing in rain barrels, cisterns, etc., generally teems with microscopic plants and microzoa.

Water containing much soda, potash, gypsum or salt, is not good; but usually it is not necessary to drink such waters, as there are few places in the Missouri and upper Mississippi valleys where good potable water may not be obtained. Surface-water that has stood for several days should not be used. Creek or river waters may be used if far enough below any source of pollution for the waters to become thoroughly aerated in transit; otherwise boiling is beneficial or may even be necessary. Water obtained from shallow wells, or from within three feet of the surface, should not be used unless the source be subterranean, as in a spring.

If there be any source of contamination in a neighborhood, the

danger zone in the ground is in the form of a truncated cone with its summit at the surface of the danger source, and its sides falling off at an angle of thirty degrees from the horizontal all around, but at a less and broader angle in the direction of waterflow. The area of safety beyond such a source is not less than 100 feet; even 150 feet is better, especially in direction of waterflow, or if the soil be sandy or porous. A well in the vicinity of such a source of danger draws the danger toward it, and extends the danger area in that direction. A driven well in such a place is not necessarily unsafe unless the soil should be very porous and the well too shallow, or not remote enough. An open well should have its wall cemented from bedrock up, or at least for eighteen feet from the surface down, so as to exclude all surface-water.

To sum up: Every tree seed contains a chemical laboratory upon a small scale, the capacity of which is increased according to its environments. Water carries, by aid of the ordinary forces of nature, such as surface-tension, cohesion, adhesion, capillarity, and osmosis, under control of temperature and electrical conditions, the food necessary for the full development of any tree, and carries it to the spot needed, even to the summit of the tallest tree. The tree itself adapts itself to its requirements and surroundings, thus enabling the water to fulfil its mission.